Seddig, K.; Jochem, P.; Fichtner, W. (2014).

Fleets of electric vehicles as adjustable loads - Facilitating the integration of electricity generation by renewable energy sources.

Energy and the Economy, 37th IAEE International Conference, New York City, USA, June, 15-18, 2014, 1-16.

FLEETS OF ELECTRIC VEHICLES AS ADJUSTABLE LOADS - FACILITATING THE INTEGRATION OF ELECTRICITY GENERATION BY RENEWABLE ENERGY SOURCES

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Abstract

This paper addresses the possibilities of using commercial and private fleets of electric vehicles (EVs) as controllable loads (i.e. controllable electricity consumption in time and power). It addresses the quantification of their load shifting potential [1], considering given mobility patterns, limits of local charging infrastructure, and different types of customers. Hereby, the main focus is on the integration of renewable energy sources (RES) (i. e. photovoltaic (PV)). The prospect of uncoordinated charging is explored. Furthermore, the potential of CO_2 emission reduction by EV and the different perspective of various fleets of EV are analyzed. The assessment is based on a multi-agent based simulation platform. The results show that with the respecting scheduling algorithm PV is very capable for the integration into the charging process of EV. Especially commuters have a high potential to adapt their charging behavior towards PV integration.

1 Introduction

1.1 Electric vehicles in the transformation process of the power grid

The "Energy Turnaround" in Germany aims to reduce fossil fuel usage in favor of RES in order to decrease greenhouse gas emissions. In the transportation sector, a transition from combustion engine based vehicles to electric vehicles (EVs) can support this objective. Another objective of the German and European energy turnaround is to improve energy efficiency. Comparing EV and combustion engines shows that the engine efficiency of EVs is significantly higher. However, the EV efficiency is depending on the power plant portfolio and ranges from 20 up to 80 % (cf. [2] or [3]). Therefore, this can be one step towards reducing energy use (and decrease the high oil dependence of Germany).

Due to the growing share of RES in the power generation mix, the fluctuation of the supply side increases and this is hardly controllable. This is a downside of the renewable energies. To ensure the stability of the power grid, broad investment programs in grid and storage appliances will be launched. Other alternatives are seen in demand response (DR) measures and investments in more flexible power plant technologies. Hence, the charging of EV might act as controllable loads in storing energy during times of oversupply in the future.

A foreseen increasing share of EVs in the market [4] might affect the grid load (i.e. peak power) considerably – in the low voltage grids [5] in particular. Furthermore, the average energy consumption of a representative household is more or less doubled by using EVs – even though the national energy consumption is only increased by a few percent (cf. [6] and [7]). Through DR measures EV can be used as a flexible load in order to overcome the resulting challenges in residential low voltages grids. Current charging processes already incorporate this intelligence from a technology perspective (IEC 61851-1). Hence, the charging of EV fleets is a potential load which can be shifted with the help of suitable charging coordination. This might lead to a stabilization of the grid and it could be used as a balancing capacity. The corresponding load shifting potentials might equalize the supply side fluctuations and could therefore help to increase the share of electricity generation by RES (cf. [7] and [8]). Hence, it might be possible to avoid an increase of peaks, so called 'peak shaving' and as well the opposite which is 'valley filling' in times of low load [9]. The former would also improve the integration of photovoltaic (PV). However, those measurements might influence the base load. Furthermore, a release of the grid and an increase of the capacity utilization of conventional power plants (i.e. increasing of profitability) can be achieved.

In Europe high standards apply for passenger cars based on the European Regulation No. 443/2009 [24]. In 2020 an average goal of 95 g CO_2/km is aimed for new registrations. This target seems to be challenging with combustion engine based vehicles. EV are often seen as a more efficient and cleaner technology which could help to reduce CO_2 emissions. However, in order to achieve the emission reduction of greenhouse gases in Germany by 40 % in 2020, still more steps need to be implemented. One sector to start with could be the transportation sector and in therein the usage of EV. In comparison to other sectors, the transportation sector in the EU 27 has still an increased CO_2 emissions contribution in the last years [16]. Apart from that, especially since the European commission already discusses new targets value of round about 70 g CO_2/km for the year 2030.

1.2 Objective and procedure

The illustrated changes in the transportation and energy sector pose challenges for the power grid. Therefore, this paper examines how different fleets of EV affect the power grid and in how far they can use a synergetic charging infrastructure e. g. in a parking garage. Applying different charging strategies, the question arises, whether a higher usage of the charging infrastructure can be achieved. One considered affect is the integration of RES in the charging process. How much PV can be generated and used for charging the different fleets of EV and hence contribute to a reduction of CO_2 emissions? Can smart charging strategies and the considered fleets of EV help with DR measurements to release the power grid?

The paper is structured in the following five sections: The next section describes the data input. Included are three different types of EV fleets (i. e. commercial fleets, long term parker and short term parker), the electricity generation from RES and the corresponding CO_2 emissions for EVs. The methodological approach is presented in chapter three. Chapter four discusses the results from the different input values of the previous sections, depending on the different chosen scenarios. Chapter five closes with a conclusion and a short outlook.

2 Data

For the development of the system environment, different data was used to develop synthetically customers for the EV fleets with different mobility patterns. Hereby internal combustion engine vehicles (ICEV) data was applied for EV. In this paper all of the EV fleets have in common that parking time is a possible time for charging. This assumption is important for the load shifting potential. Moreover, the data for RES, especially PV can be used and therewith the corresponding CO_2 emissions are examined.

The project ‘Integrated fleet and charge management’ from the program ‘Showcase electromobility’ of the German Federal Government is used as a data source.

2.1 Fleets of electric vehicles

In the context of this paper, three different types of EV fleets are considered. This includes customers who use a parking garage for private use and in their leisure time (i), i. e. short term parker. Secondly, people who park during the day at work, who are most likely commuters (ii). Thirdly, a business fleet (iii) is regarded which has customers who can book the cars by a fleet management system and for business trips purposes.

(i) Short term parker

People who usually use public parking ground for private use like shopping or leisure activities are included in that type of EV fleet. For the regarded parking garage, the average length of stay for short term parker was 3.5 hours during a weekday (cf. Figure 1) [26]. Other data sources for ICEV imply in average only a parking duration of about 1 to 2 hour for short term parker [23].

(ii) Long term parker (commuter)

The EV fleet of this group is characterized through private person using their car to come to work and leave the working place after their working day by car. The average length of stay is about 8 hours, having a peak at 10 hours (see Figure 1). Those data supports the assumption that, in most cases, the regarded fleets of EV belongs to commuters. The distribution of the arrival time and departure time proves this statement. Comparing this data to other sources like the ‘Automobile data in Germany 2010’ (KiD) data for ICEV, the duration of the stay is as well in average about 7.5 h, peaking 9.5 h.

The travel distances are distinguished for all three types of the EV fleets using the KiD data [23]. Commercial journeys cover the longest distances where people who use their car for private matters, such as shopping or leisure activities, in average drive 13 km have a peak within 5 km (see Figure 2). In average commuters’ distances are 19 km.

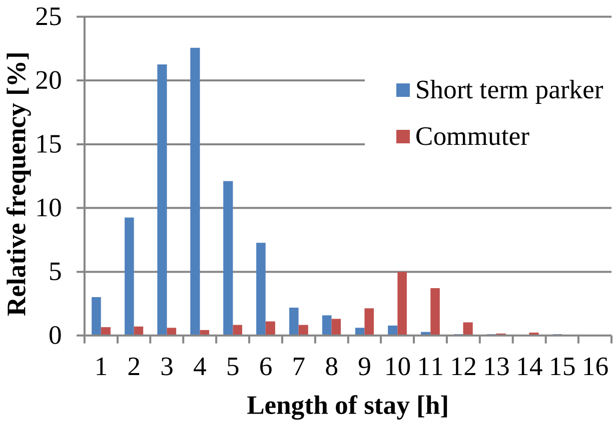

Figure 1: Parking duration of EV fleets during a weekday; Data source [26]

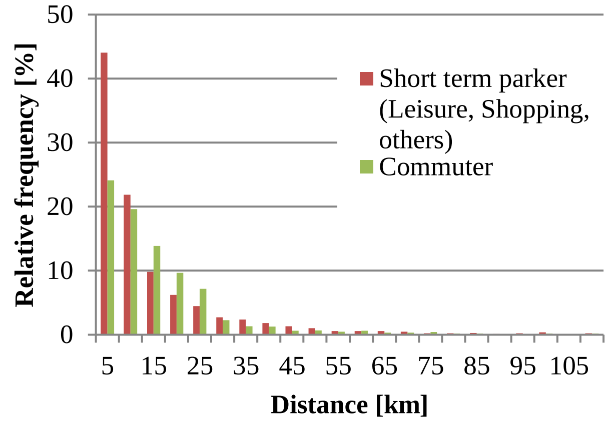

Figure 2: Distance of trip; Data source [23]

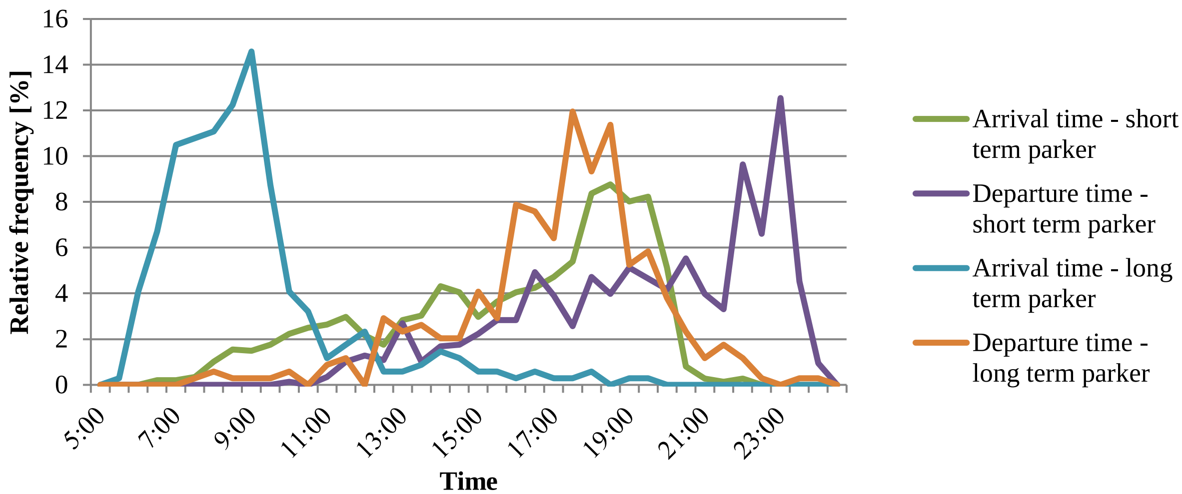

Figure 3: Share of the different EV fleets - parking during a weekday in car parks; Data source [26]

(iii) Commercial fleets

The business fleet’s mobility patterns were generated by using the KiD [23]. This data was statistically analyzed to derive synthetical driving profiles. Based on these data probability distributions of driven distances, departing times as well as length of trip were approximated [14]. For the simulation model, data for commercial vehicles was examined.

Over the day the allocation of the different fleets of EV show in the regarded parking garage, that the fleets of short term parker and long term parker have the largest share for the occupancy.

2.2 Renewable energy sources

The integration of RES into the power grid with the help of EVs is one research field which is investigated quite often. The focus of the existing literature is hereby mainly on wind and PV generation [13]. Taking a closer look at the situation in Germany, the share of RES has risen to a new all-time high of 23.4 % (147 TWh) of the electricity generation in Germany in the year 2013, compared with 22.8 % (143.5 TWh) in 2012 [15]. Due to funding through the renewable energies act, there was an enlargement of PV facilities in the recent years. Especially the power generation through PV had an increase of 6.3 % in the year 2013, compared to the previous year 2012. This results to 4.5 % of the electricity generation from a total of 629 TWh in Germany in the year 2013. Hereby an increase from the year 2012 to the end of the year 2013 was achieved from about 28 000 MWh and 32.64 GW_p installed capacity of 35.7 GW_p installed capacity, producing 29 700 MWh in 2013 (see Figure 5). On sunny days it is possible that 30-40 % of the electricity consumption for a particular time is covered by PV energy [12].

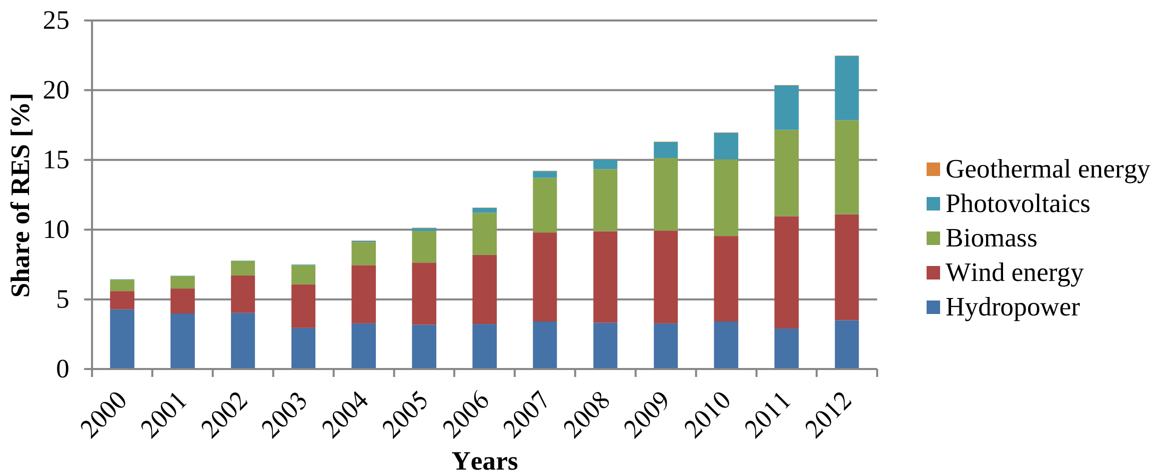

Figure 4: Development of electricity consumption from RES in German from 2000 - 2012; Data source [18]

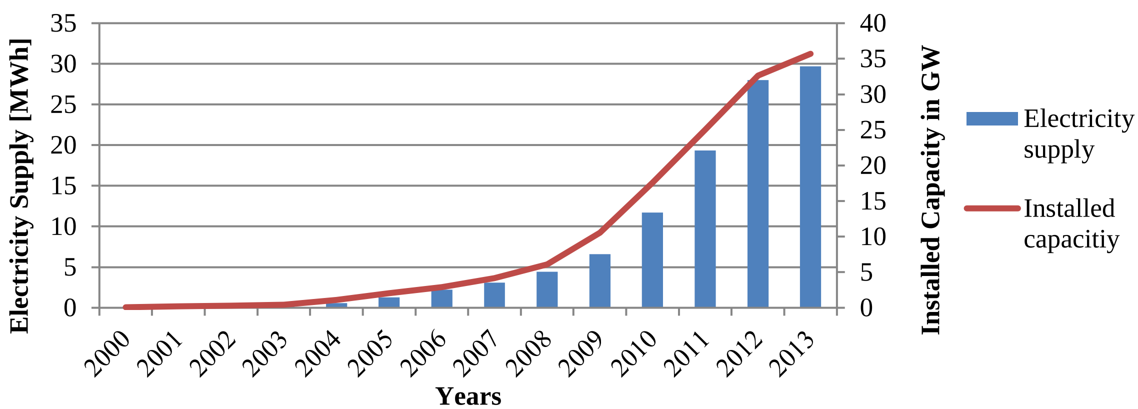

Figure 5: Development of electricity supply of installed capacity and from PV plants in Germany; Data source [18], [12]

2.3 Electricity generation through photovoltaic

Apart from having data of the PV generation for Germany, it is especially interesting how much energy a special area can supply. Due to the variability of the area where to produce PV and hence the feed-in of the generated energy, even for own consumption, makes the PV generation especially attractive [13].

The global radiation and the installed capacity of the PV plants can be used to determine the load curve for the regarded weeks in the area of Stuttgart, Germany. The total radiation also depends on the region, the overall value of the year alternates in Germany between 950 kWh/m²/a in the northern parts up to 1 250 kWh/m²/a in the southern parts [12]. Figure 6 reveals that there is a high potential for electricity generation in the summer months. Besides the regional variation there is also a time fluctuation over the day. However, it also points out that the radiation has a high volatility time as well as amount wise. Hence, it can be the case that on some days, the produced amount of energy on a day in November, April or February is the same. Therefore, the efficiency is varying and depending on different factors, e g. clouds.

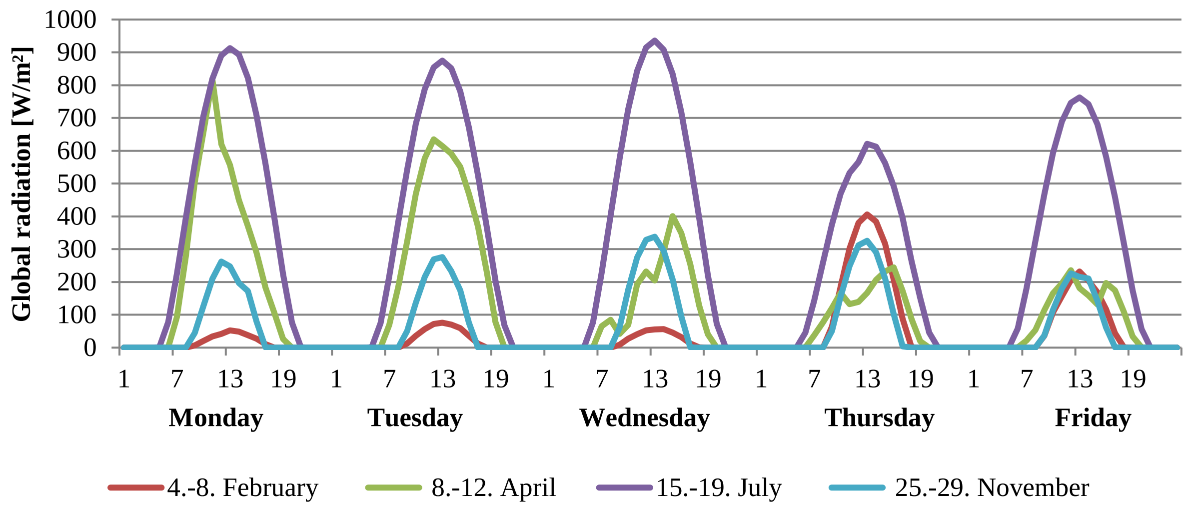

Figure 6: Global radiation for some weekdays of Stuttgart (Germany) area in 2013; Data source [17]

With respect to the regarded parking garage, the roof area is limited. The assumption on efficiency for the PV modules is 100 W/m², resulting in a maximum usable potential of 200 kW_p [20]. For the PV modules more specified assumptions such as adapting the orientation of the modules, as well as the angle which depends on the altitude of the sun over a day, can be integrated in the future. This way, the maximal usable potential of generated power can be increased.

The global radiation for the region of Stuttgart in Germany was about 1090 kWh/m²/a with an average value of 124.5 W/m² in 2013. Hence, the generated energy by the PV of the roof of the parking garage (2 000 m²) might be about 218 MWh.

2.4 CO_2 Emissions

In order to determine the emissions caused by using EV, different measures are possible. Depending on the calculation method e. g. annual electricity mix, marginal electricity mix or average time-dependent mix (cf. [19]) different values for CO_2 emissions for EV will appear depending on whether it is measured in kg CO_2/kWh_{el} or g CO_2/km. Those values of the average mix also vary between countries, as there are differences in the electricity mix (cf. Table 1). Taking Brazil for instance into consideration, the low value of the average CO_2 emissions results from a high electricity generation by hydropower. In comparison the electricity generation in France is formed by a high share of nuclear power, however, this results as well to low CO_2 emissions.

Country	Average CO_2 Emission in	
	g CO_2/kWh_{el}	g CO_2/km*
Austria	215	43
Brazil	68	14
Canada	167	33
People's Rep. of China	764	153
Denmark	315	63
France	61	12
Germany	477	95
India	856	171
Japan	497	99
South Africa	869	174
Sweden	17	3
Thailand	522	104
Turkey	472	94
United Kingdom	441	88
United States	503	101
World	**536**	**107**

Table 1: CO_2 emissions of EV in different countries in 2011; Data source [25];
*** Calculated with an assumed EV electricity consumption of 0.2 kWh/km.**

3 Method

3.1 Multi-agent based simulation

For answering the research questions, a multi-agent based simulation tool is used. It allows to represent diverse agents interacting with each other. Agents are defined to characterize EV, customers with individual driving profiles and preferences (incl. bounded rationality), the fleet management system, electricity feed-in of PV and charging stations. Different scenarios are analyzed applying statistical methods in order to identify charging strategies for different system conditions.

In a multi-agent based simulation the agents and their interaction with the environment can be represented well and therein different technical characteristics of the model are integrated. The agents are still homogeneous in their selected behavior. Thus changes and adaption of behavior rules can be integrated quickly. Communication, i. e. the transmission and reception of data, is due to an existing interface, possible. This allows e. g. to transmit status changes. Input data can be implemented and different decision rules placed to analyze the simulation status. The user requests for the commercial fleet are made on a fleet management system, which has a complete overview of the available vehicles and their status (including state of charge (SoC) or charging). This is relevant for the central control at the charging process of the individual EVs and the allocation of EVs to the users' requests.

All EV have the same parameters, including a battery capacity of 24 kWh and an average electricity consumption of the EVs of 0.2 kWh/km[1] as well as a constant charging curve for the battery, depending on the charging mode. For each EV a charging station is available and for the duration of the parking time, it is connected to the charging point.

The calculations are performed in a 1-minute resolution ($t \in \{1, \ldots, T\}$). A limitation of the power input is foreseen (see equation 1) and it depends on the maximum power of the building connection (P_{BC}). As long as there is enough charging power available for the EV (P_{EVSE}) at the charging points $i \in \{1, \ldots, I\}$, the EV can charge.

$$P_{BC} \geq \sum_i P_{EVSE_{i,t}} \quad \forall \ t; \qquad (1)$$

with
P_{BC} Maximum power of building connection
P_{EVSE} Charging power of EV at charging point i

If the maximum power is reached no new customer request for charging will be accepted, until charging power is available (due to a finished charging process from another EV). Hence, if a charging request of an EV is denied the success rate drops. That means the overall success rate explains, whether it is possible to charge or not, if e. g. a short term parker arrives at the parking garage. This is depending on the available charging power and the requested amount of energy in a certain time.

Further assumptions for the simulation model include ex-ante fully known information about mobility pattern and PV feed-in data. The driving behavior is approximated by different probability distributions for departure and arrival time as well as trip distances for each of the three types of EV fleets.

3.2 Charging strategies

Different charging strategies for fleets of EV need to be evaluated. The examined commercial fleets of EV are organized in a fleet management system. Hence, the overall problem for charging is a scheduling problem. Constraints, which are based on a limitation of the available amount of electricity for charging the fleets or by technical grid constraints, arise. If there is no charging strategy implemented ('uncontrolled charging'), an EV will charge as soon as it returns to the charging station and the following conditions are fulfilled: Firstly, it must be completely connected to a charging point (including authorization (cf. e.g.

[1] A reference value is e. g. Nissan Leaf [22].

ISO15118) etc.) and secondly, sufficient charging power must be available (i.e. with respect to the underlying energy system grid). If the load is limited, the charging process has to be postponed [10]. Two types of charging points are considered: Mode 2[2] (3.7 kW) and Mode 3 charging (up to 22 kW).

The charging strategy is implemented with two different assumptions for the required amount of charging load. The first scenario assumes that all fleets of EV want to charge their car completely up to a SoC of 100 %, 'strategy SoC 100'. Thereby a much higher usage of the charging infrastructure is seen and less EV can charge during that time. The second scenario implies that all EVs have a SoC, which is sufficient for their planned trip and an additional safety buffer, 'strategy SoC next trip'. This enables a higher flexibility in terms of when to charge EV. Especially commuters who stay for about 9 hours have a potential to shift their load process. The same works for commercial fleets, which have a high potential to shift their charging process to the night [14]. In the German commercial transport sector different fleets can be identified to be used for 'green' charging, i. e. German postal services [21]. The assumption that the whole parking time can be used for charging is important when it comes to the implementation of different charging strategies.

In this paper identified challenges are, for instance, how the different types of customers are affected by synergetic charging, which means a customer uses a common public charging infrastructure, e. g. in a parking garage. In such an environment – apart from having not enough charging points – other problems, such as grid restrictions, lead to further aspects, which need to be considered. Under these circumstances, the charging of different fleets needs corresponding prioritization rules that release the grid and simultaneously satisfy all customer requirements. The different fleets include commercial fleets, where the booking is managed through a fleet management system and private EV during short as well as long-term parking conditions (during working hours or during night) at a charging point. In this simulation, all three fleets have the same priority for charging.

3.3 Scenarios

In order to examine the research questions, different concepts need to be implemented in the simulation model. Therefore, the uncoordinated charging strategy and therein different assumptions are applied.

Uncoordinated charging (Mode 2 or Mode 3)	**Summer PV**	**Winter PV**	**Without PV**
Strategy SoC 100	x		x
Strategy SoC next trip			

Table 2: Overview of chosen scenarios

Moreover, three possibilities for PV feed-in data (namely summer, winter or without PV) are analyzed. At the same time the electricity share coming from PV for EV is examined. Hereby is in particular the difference of the three fleets of EV explored. Additionally there are two different charging modes (Mode 2 and Mode 3) of the EVs analyzed and their impact on the charging power is analyzed.

[2] Following the specification of charging modes by IEC 61851-1.

4 Results and discussion

4.1 Impacts of the charging strategies

First, the impact of the different scenarios is shown and a closer look on difference of the scenarios is taken, especially how far the three fleets of EV can contribute to an improved PV integration.

In order to examine a higher impact on the charging power the scenarios with the completely charging of the EVs is displayed. For all scenarios 75 commercial EVs, 150 long term and 150 short term EVs are considered. Twice as much energy is required for charging, if there is a distinction made between ‘strategy SoC 100’ and ‘strategy SoC next trip’. If the scenario without PV integration is considered, the success rate for the requests of EVs drop for the long term as well as short term parker to about 75 %. The accumulated charging power is over half of the time at the chosen global load limit of 100 kW (cf. Figure 7). However, all other scenarios have nearly a success rate of 100 % for each EV fleet.

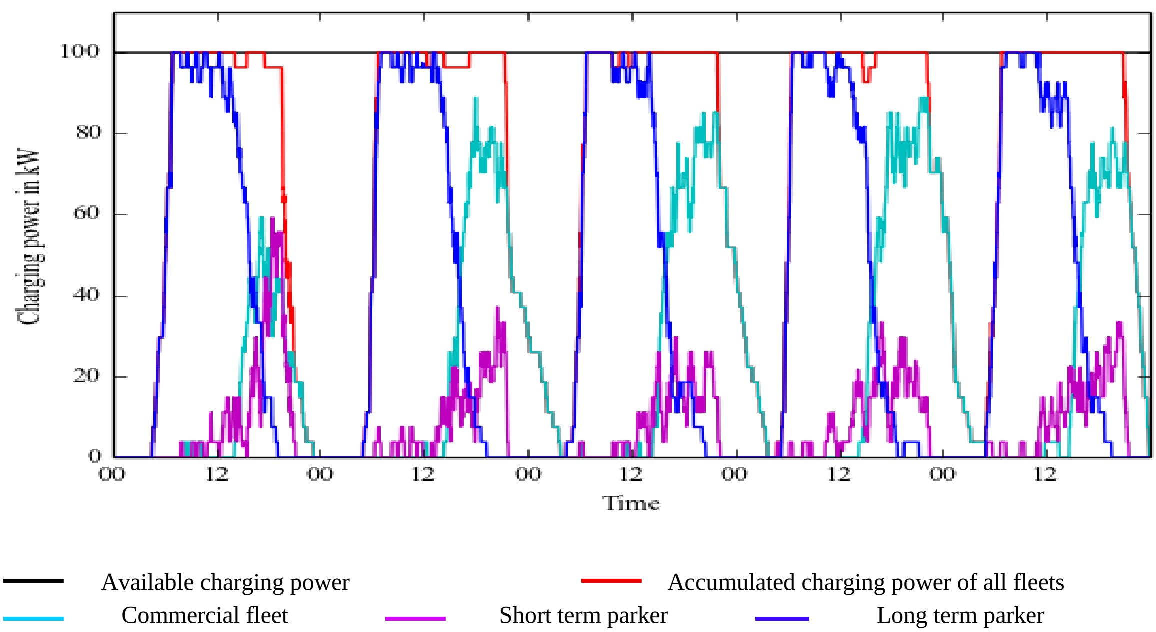

Figure 7: Accumulated charging power with uncoordinated charging by 3.7 kW without PV

The summer week in 2013 implies a high possibility for load shifting as the available charging power is only a few times fully used (see Figure 8). According to the parking time, it is possible to shift during the day the charging process of the long term parkers. Commercial fleets have in particular a potential for load shifting during the night.

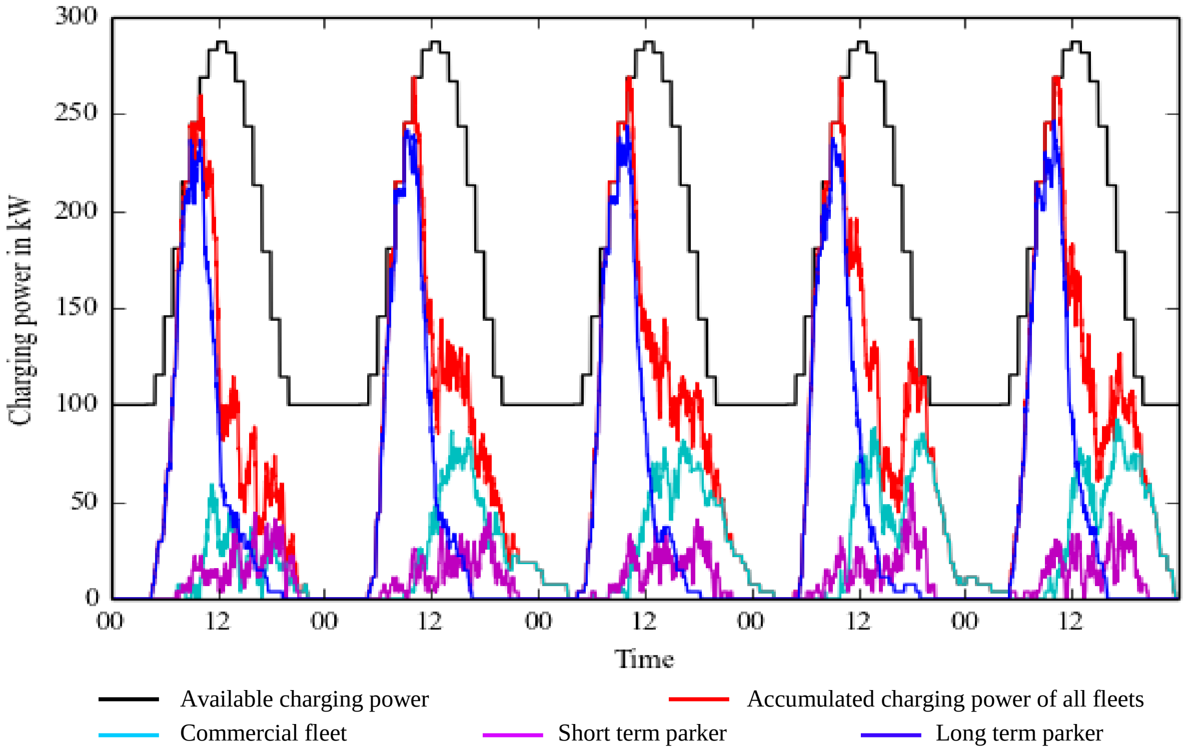

Figure 8: Accumulated charging power with uncoordinated charging by 3.7 kW with summer PV

Taking the charging Mode 3 for all EV into consideration it appears, that the charging curve for the fleets of EV changes and the time for charging is reduced by a couple of hours. Hence, in that case no charging over night is necessary, however, still possible for the commercial fleets. Therefore, a higher flexibility for load shifting is available.

The results indicate that the load shifting potential of fleets of EV facilitates the integration of electricity generation by PV and releases the grid. Hence, even for several closely positioned Mode 3 charging points, an expensive grid extension can be avoided through the corresponding charging scheduling algorithm.

4.2 Load shift potential with integrated renewable energy sources

In order to analyze the potential for the integration of PV, the RES charging strategy for summer and winter is used. The summer scenario for PV feed-in is based on a week in July in 2013, however, with an adaption. The maximum day of this week is used to construct one week with global radiation like this for all days in a week, in order to have in a certain way a best case scenario for PV. The winter scenario is done similarly, however, based on a low feed-in day in February 2013. This generates two extreme scenarios. The corresponding global radiation (see Figure 6) was about 8 420 kWh. Hence, this is the resulting total feed-in for PV. The overall consumption of electricity for the charging process of the fleets of EVs for this week was about 10 000 kWh. Hence, 6 890 kWh (82 %) of the electricity could be supplied by the PV plants, if uncoordinated charging 'using PV energy first', is applied (see Figure 9).

For the week in February merely an electricity supply of PV by 333 kWh was possible (see Figure 6). Consequently, the overall contribution of the PV production for the charging load of the EVs was only about 5 %.

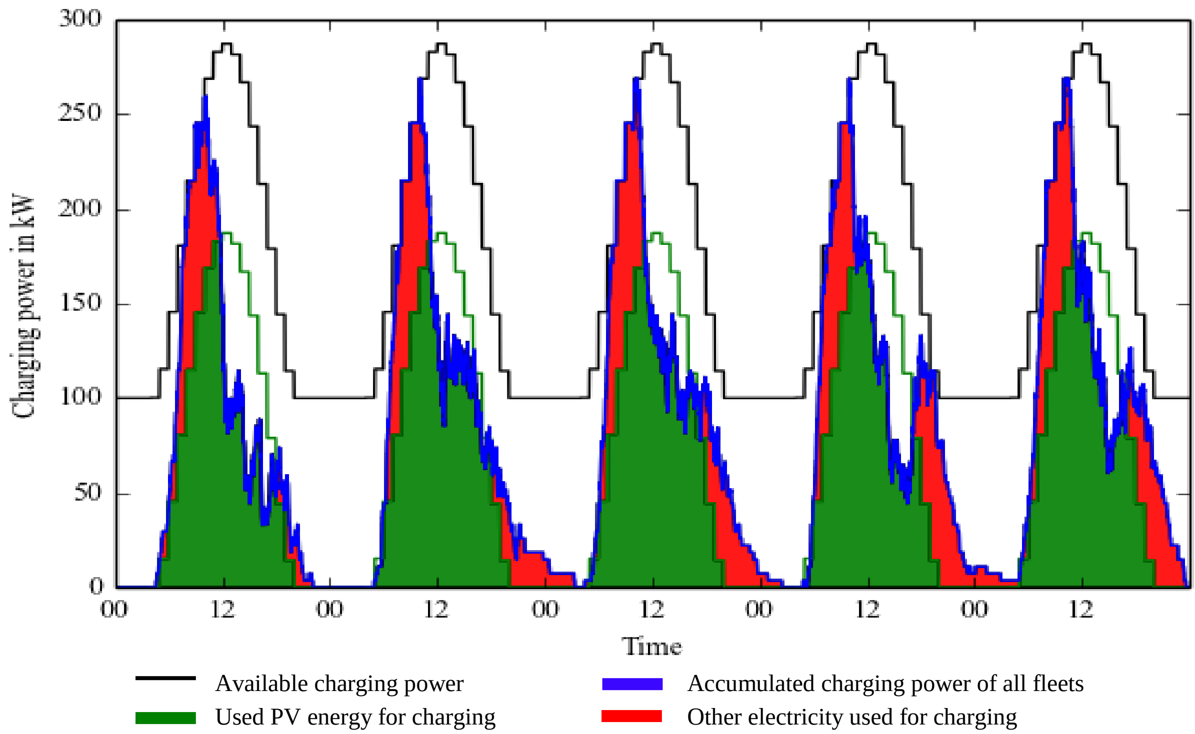

Figure 9: Accumulated charging load by 3.7 kW using preferable PV

Moreover, calculation showed that due to the parking time of the commuters the share of PV usage could even be improved from the 82 % up to 100 %, depending on the day and inquiries for charging. This is possible, if a smart charging strategy for the best possible integration of RES is applied and some of the charging processes are postponed.

4.3 CO_2 emission reduction

Accompanied by a higher share of RES for charging, is the increasing potential for CO_2 emissions reduction of EVs. This is a major reason for EV users for their decision [11] whether or not to purchase an EV. The people, who drive EV for their private use, are especially aware of the advantages from EV. Hence, with the combination of fuel-free driving and even obtaining the electricity by RES makes it very attractive for EV users.

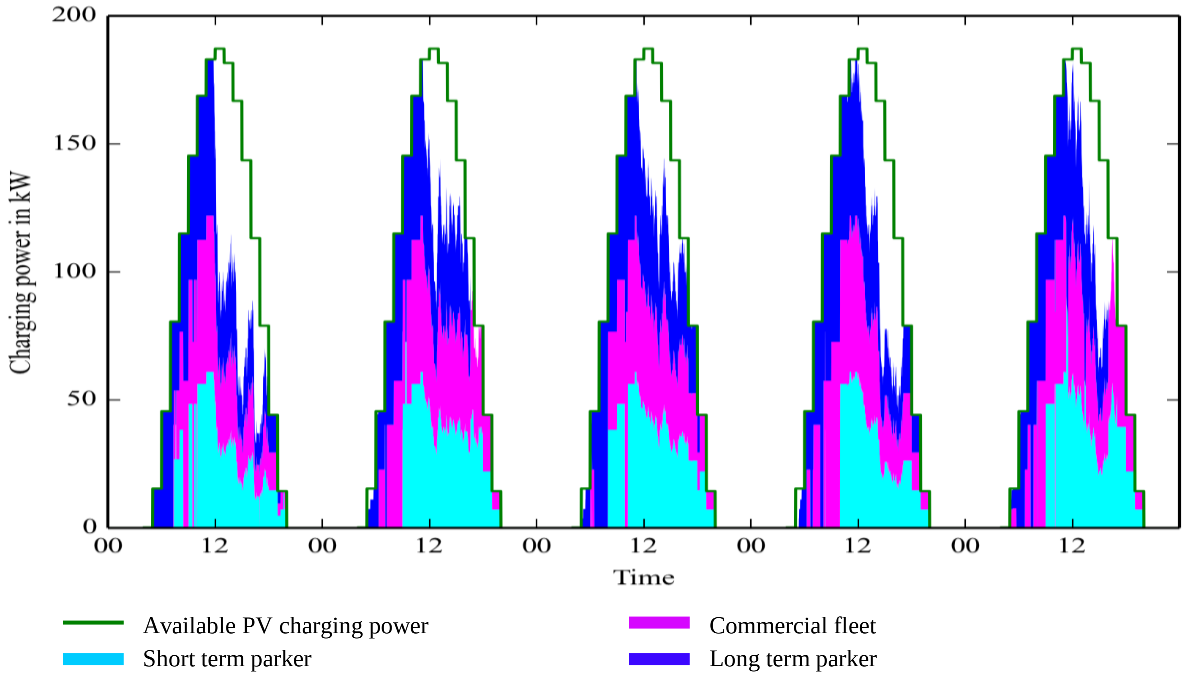

Figure 10: Accumulated charging load in detail for each EV fleet by 3.7 kW using preferable PV

In order to evaluate the potential for CO_2 emission reduction, as an example the summer week is used. With the applied uncoordinated charging strategy a reduction of round about 3.3 t CO_2 could be achieved with the production of 6 890 kWh, if the German average CO_2 emission factor for the energy mix is used (see 2.4). Taking into consideration the energy mix table of different countries (see Table 1), it could be possible to reduce even more CO_2 emissions, if the PV production is in a different country (e. g. a parking garage with integrated PV in the United States). Taking a closer look of the CO_2 reduction potential of the three EV fleets (cf. Figure 10), long term parker have saved 1.23 t CO_2, short term parker 1.12 t CO_2, and commercial fleets 0.94 t CO_2. Considering an adapted charging algorithm for the best-fit integration of PV, even higher CO_2 reductions are possible. Especially the long term parker could even save up to 1.9 t CO_2 as they have a potential for load shifting over the day.

Considering one year in the regarded parking garage, taking the sun hours in 2013 into consideration would account for an electricity supply of about 218 MWh which could be a CO_2 reduction of about 104 t CO_2.

4.4 Critical review

The developed simulation model is based on the database of the KiD and from data of the project ‘Integrated fleet and charge management’. Therein the commercial fleet is a broad fleet, which has only a limited set of data for length of stay. Thus, more specific data could validate the value of the results. The simulation model contains no other technical restrictions, such as the communication between vehicle and charging station. Moreover, no specific charge curves for the EVs are integrated. The results presented in this work have no optimized charging strategies. Effects of optimized charging strategies with complete information about future bookings could be analyzed in a next step. However, the fully ex-ante known information are also a constraint of the underlying simulation model.

Apart from that, all three different fleets have the same prioritization for charging. An introduction of prioritization rules and those linked with monetary values are foreseen for future research.

5 Conclusion and outlook

This paper gives an outline of load shift potentials for different fleets of EV using a multi-agent based simulation. The model includes different charging points, charging strategies, and charging scheduling algorithms for different system conditions. The resulting technical load shifting potentials are, for most EV, surprisingly high. An integration of (local) electricity generation by RES is, therefore, very promising and leads to a release of the local electricity grid. The generated PV energy of the regarded parking garage can be used nearly up to 100 % all over the year, if a smart charging schedule algorithm for the integration of the PV is implemented. Especially the charging behavior of commuters can be adapted towards PV integration. This leads (especially in Germany) to a reduction of CO_2 emissions, which is highly desired by current EV users. Commercial fleets charging processes can be shifted towards night time which might be interesting for grid support.

For further research wind energy can be integrated as one part of the charging power. One benefit would be that wind has a different feed-into the grid than PV. Hence, there could be more possibilities to shift the charging loads of the EV accordingly. Furthermore, a charging scheduling algorithm could allow an improvement in the usage of public charging stations – which enhance its profitability.

Moreover, an implementation of monetary values is regarding economically aspects reasonable. Charging strategies could be adapted to implemented prices and different business models for the involved parties could be developed. This could influence prioritization of fleets or the energy amount for charging. The latter depends whether the individual customer is willing to pay or not.

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